

7-2009

NDE of lumber and natural fiber based products with air coupled ultrasound

David K. Hsu
Iowa State University

David Utrata
Iowa State University, heydave@iastate.edu

Monlin Kuo
Iowa State University, mlkuo@iastate.edu

Follow this and additional works at: http://lib.dr.iastate.edu/cnde_conf

 Part of the [Materials Science and Engineering Commons](#), [Natural Resources Management and Policy Commons](#), and the [Structures and Materials Commons](#)

The complete bibliographic information for this item can be found at http://lib.dr.iastate.edu/cnde_conf/73. For information on how to cite this item, please visit <http://lib.dr.iastate.edu/howtocite.html>.

NDE OF LUMBER AND NATURAL FIBER BASED PRODUCTS WITH AIR COUPLED ULTRASOUND

David K. Hsu, David Utrata, and Monlin Kuo

Citation: *AIP Conf. Proc.* **1211**, 1533 (2010); doi: 10.1063/1.3362250

View online: <http://dx.doi.org/10.1063/1.3362250>

View Table of Contents: <http://proceedings.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=1211&Issue=1>

Published by the [American Institute of Physics](#).

Related Articles

Physical interpretation and separation of eddy current pulsed thermography

J. Appl. Phys. **113**, 064101 (2013)

Development of eddy current testing system for inspection of combustion chambers of liquid rocket engines

Rev. Sci. Instrum. **84**, 014701 (2013)

Eddy current effects in plain and hollow cylinders spinning inside homogeneous magnetic fields: Application to magnetic resonance

J. Chem. Phys. **137**, 154201 (2012)

Defect characterisation based on heat diffusion using induction thermography testing

Rev. Sci. Instrum. **83**, 104702 (2012)

Fully automated measurement setup for non-destructive characterization of thermoelectric materials near room temperature

Rev. Sci. Instrum. **83**, 074904 (2012)

Additional information on AIP Conf. Proc.

Journal Homepage: <http://proceedings.aip.org/>

Journal Information: http://proceedings.aip.org/about/about_the_proceedings

Top downloads: http://proceedings.aip.org/dbt/most_downloaded.jsp?KEY=APCPCS

Information for Authors: http://proceedings.aip.org/authors/information_for_authors

ADVERTISEMENT

AIPAdvances

Submit Now

**Explore AIP's new
open-access journal**

- **Article-level metrics
now available**
- **Join the conversation!
Rate & comment on articles**

NDE OF LUMBER AND NATURAL FIBER BASED PRODUCTS WITH AIR COUPLED ULTRASOUND

David K. Hsu¹, David Utrata¹, and Monlin Kuo²

¹Center for Nondestructive Evaluation, Iowa State University, Ames, Iowa 50011

²Department of Natural Resource Ecology and Management, Iowa State University, Ames, Iowa, 50011

ABSTRACT. Due to the porous nature of wood and natural fiber based products, conventional fluid or gel coupled ultrasonic inspection is unsuitable. Air-coupled ultrasonic transmission scanning, being non-contact, is ideally suited for inspecting lumber, wood and natural fiber based products. We report here several successful applications of air-coupled ultrasound for the inspection of wood. Air-coupled ultrasonic scan at 120 kHz can easily detect “sinker-stock” lumber in which bacterial damage of ray tissue cells had occurred during anaerobic pond storage. Channels in ash lumber board caused by insect bore were imaged in transmission scan. Delamination and material inhomogeneities were mapped out in manufactured wood and natural fiber products including medium density fiberboards, compression molded shredded waste wood with formaldehyde resin, and acoustic panels molded with kenaf fibers. The study has demonstrated some of the capabilities of air-coupled ultrasound in the NDE of forest products.

Keywords: Air Coupled Ultrasound, Wood, Lumber, Natural Fiber Products

PACS: 81.70.-g

INTRODUCTION

Ultrasound is a useful nondestructive evaluation (NDE) tool for wood, but the “coupling” between the ultrasonic transducer and the wood has always been a problem area. Conventional ultrasonic testing relies on a liquid or gel couplant [1,2]. In the contact mode of inspection, the sound energy is transmitted through a thin layer of oil or gel between the transducer face and the test object. For structures conducive to immersion in water, ultrasonic inspection and scans are conducted in an immersion tank where both the structure and the ultrasonic transducers are immersed. In the aerospace industry, “squitter” ultrasonic scan systems are used, in which the beam of sound is carried by a jet of water that impinges on the test object. In the inspection of wood, the need of a couplant is often undesirable or inconvenient. An ideal solution is to use air-coupled ultrasound and conduct the inspection in a non-contact fashion [3-5].

Air-coupled ultrasonic transducers were first commercialized about twenty years ago. After considerable development and improvement [6,7], the technology has gain maturity; off-the-shelf air coupled transducers and the associated electronics are available for industrial use. Due to the high attenuation of sound propagating in the atmosphere, air-coupled ultrasonic testing is typically carried out at frequencies up to a few hundred kilohertz. The transducers are



FIGURE 1. A piece of normal ponderosa pine lumber is being scanned with air-coupled ultrasound at 120 kHz.

driven by a “toneburst” voltage that consists of a number of cycles at the desired frequency. Air-coupled ultrasonic testing is done almost always in the through-transmission mode, with the sample situated between the transmitting transducer and the receiving transducer. Figure 1 shows an experimental setup for air-coupled through transmission ultrasonic (TTU) imaging of a normal pine lumber specimen using commercially available transducers. The 120 kHz air-coupled transducers and the pulser-receiver were purchased from QMI Inc. in Huntington Beach, California. The transmitting and receiving transducers were ganged together and scanned in a raster fashion to acquire data in the form of transmitted amplitude versus position on the sample.

In air-coupled ultrasonic inspection of solids, the transfer of sound energy through the air-solid interface is quite inefficient due to the large impedance mismatch between the air and the solid. The acoustic impedance, i.e., the product of the speed of sound and the material density, of wood is thousands of times greater than that of air. For oak wood, the ratio is about 6000:1, so that at the air-oak interface approximately 99.94% of the incidence energy is reflected back into the air and only 0.06% of the energy is transmitted into the wood. After the sound has propagated through the wood, the same inefficient energy transfer takes place at the exit surface before it is detected by the receiving transducer. The signal amplitude transmitted through the samples is therefore extremely small and requires special low-noise amplifier in the receiving circuit. In the transmission of sound through the sample, any discontinuities along the path of propagation will affect the transmitted amplitude. The presence of a void or crack would introduce an additional pair of interfaces that can substantially block the sound transmission. Defects would therefore appear as a region of low amplitude in the C-scan image.

This paper summarizes research results with the use of air-coupled ultrasound at Iowa State University in the past few years. Additional examples are also presented to demonstrate the potential of the technique for research and for products quality inspection.

BEAM SKEWING EFFECTS OF WOOD GRAIN

The propagation of sound through wood is strongly affected by the inhomogeneity and anisotropy of the wood, particularly the orientation of the wood grain. A beam of sound can be easily skewed by the wood grain oriented at an angle with respect to the propagation direction. The preferred propagation direction for a beam of sound is normal to the grain since an incident sound beam at an angle to the grain can be steered away from its original direction. Figure 2 shows this effect graphically [5]. Here the transmitting transducer is held fixed in position and the receiving transducer is scanned to make a cross-sectional image of the transmitted sound beam intensity.

CASE STUDIES AND EXAMPLES FOR APPLICATION

Detecting Ponderosa Pine Sinker-Stock Lumber

The anaerobic condition during pond storage of logs allows bacteria to destroy ray tissues, causing the logs to sink to the bottom. Lumber manufactured from sunken logs is referred to as sinker-stock lumber. One main problem with sinker-stock lumber is that it would uptake excessive preservative solution during treating. The air-coupled ultrasound scanning technique was successfully used to detect ponderosa pine sinker-stock lumber [8]. Figure 3 shows the C-scan image of a normal ponderosa pine lumber where a relatively uniform high intensity band of transmitted sound energy is imaged in the radial direction. This high level of sound energy transmission is associated with the intact ray tissues in the wood as shown in the accompanying photomicrograph.

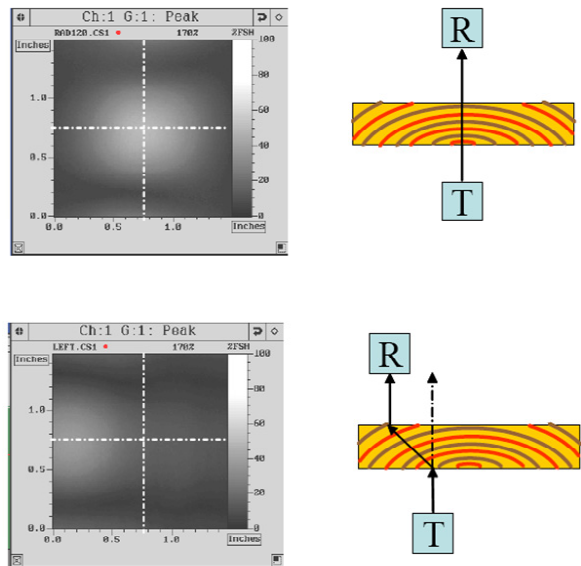


FIGURE 2. Beam skewing effect of ultrasonic propagation in lumber due to relative orientation with wood grain.

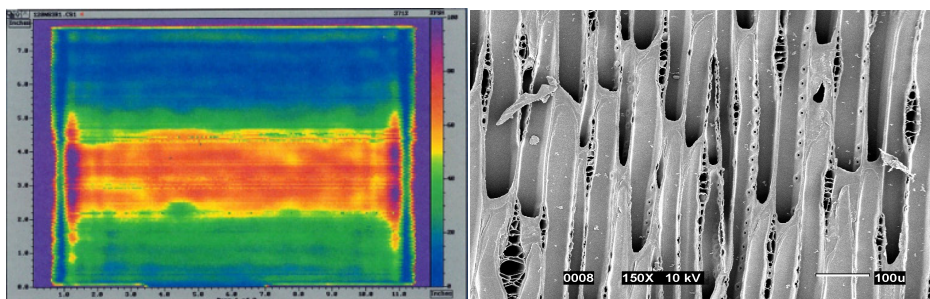


FIGURE 3. C-scan image of normal ponderosa pine lumber, showing relatively uniform high intensity band in radial direction (left) and SEM photomicrograph (right) showing the intact ray tissues.

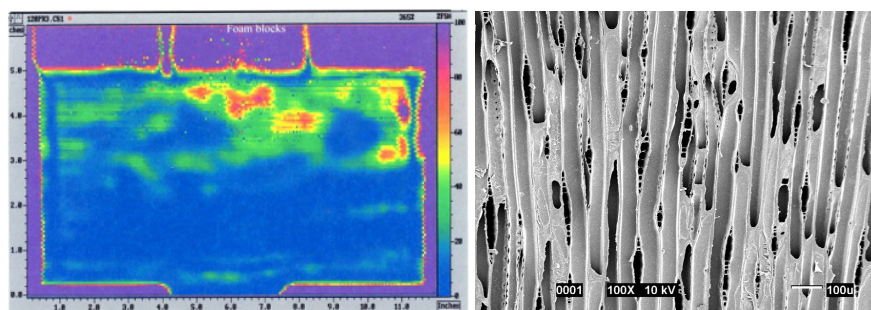


FIGURE 4. Left: C-scan image of ponderosa pine sinker-stock lumber, showing low signal intensity in radial direction with few scattered small high intensity regions. Right: SEM photomicrograph of ponderosa sinker-stock lumber, showing empty rays and fusiform rays. Note that thick-walled ray tracheids were not destroyed.

Figure 4 shows the C-scan image of a piece of sinker-stock lumber, with overall low intensity of transmitted signals in the radial direction. SEM examinations of the piece showed that thin-walled ray cells were heavily decomposed, forming continuous radial air channels which greatly reduced the intensity of ultrasound signals.

Other Lumber Defects

When a piece of pine lumber containing a tight, spiky knot not visible on one side was scanned with air-coupled ultrasound, a C-scan image was obtained as shown in Figure 5 where outline of the spiky knot is clearly displayed by low intensity signals. Wood grain diversion in the spiky knot resulted in low ultrasonic signals. Figure 6 shows a C-scan image of a piece of white ash sapwood with numerous insect tunnels made by flat-headed borers, most of which were internal. Superficial as well as internal insect tunnels are shown by tracks of low intensity signals. Although insect tunnels were tightly packed with wood debris and insect fecal pellets, density of the material packed in the tunnels was much lower than that of sound wood. The

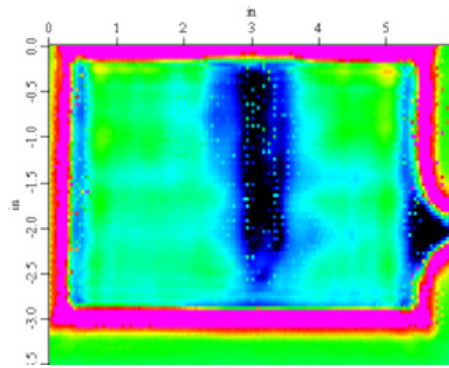


FIGURE 5. C-scan image of pine lumber containing a spiky knot shown by low intensity signals. The tight knot was not visible on one side.

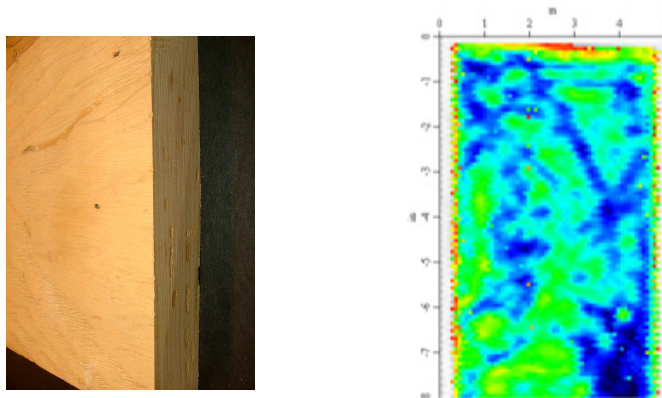


FIGURE 6. C-scan image of white ash lumber containing many superficial and internal insect tunnels shown by tracks of low intensity signals.

examples above clearly demonstrate that air-coupled ultrasound scanning can quickly detect internal lumber defects.

Wood-Based Composite Products

In the manufacturing of wood-based composite products, such as chair seats and backs, shredded waste wood is often bonded with urea-formaldehyde resin in a compression molding process. Structurally the compression molded products are quite complex as they contain shredded wood particles of irregular shape and of different size and species. The strength and durability of the composite wood products depends on the wood/resin ratio and the homogeneity of the mixture. Anomalous distribution of the end product may signal problems in the process control. Due to the heterogeneous nature of the product, ultrasonic evaluation is hampered by the strong scattering by the constituents and can be difficult. However, at the low frequency of air-coupled ultrasonic testing (in the vicinity of 100 kHz), C-scans of the signal

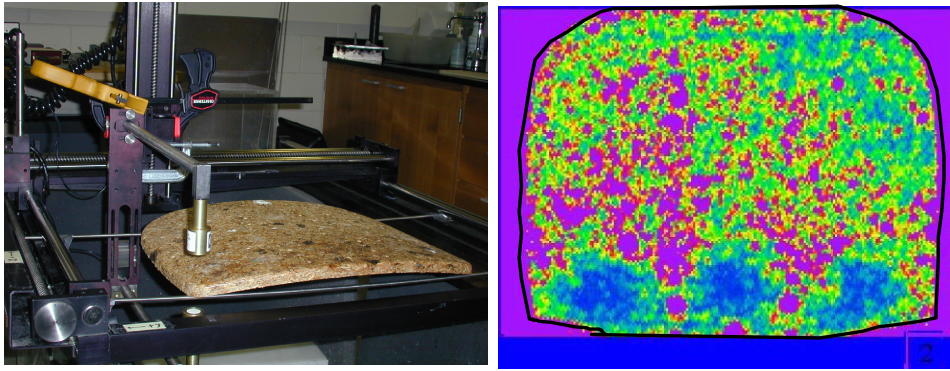


FIGURE 7. Ultrasound scanning of a molded chair seat and the resultant scan image. The scan image is 16"x15" in size.

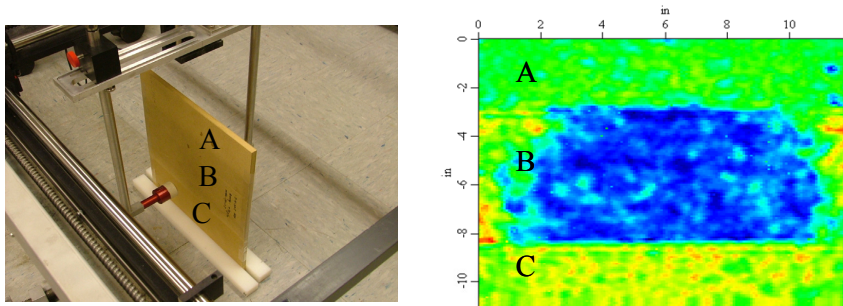


FIGURE 8. C-scan image of three MDF boards with average IB values of 0.29 MPa (Top), 0 MPa (middle) and 0.67 MPa (bottom).

amplitude can be readily used for imaging the homogeneity of the molded products. Figure 7 shows the application of 120 kHz air-coupled ultrasound on a compression molded chair seat. Features in the image were correlated to the manufacture process.

Medium density fiberboards (MDF) are widely used in the wood industry. The quality of MDF depends on their density and homogeneity. Air coupled ultrasound may be used in the assessment of the quality of MDF. In this study, three pieces of 14 cm x 35 cm x 1.27 cm ponderosa pine medium density fiberboard were edge-wise stacked and ultrasonically scanned. These MDF boards were bonded with 12% solids of different protein-based adhesive resins and pressed at 200 °C for 7 minutes to the same target density of 0.75 g/cc. The average internal bonding strength (IB) of the top, middle and bottom piece was 0.29 MPa, 0 MPa and 0.67 MPa, respectively. C-scan image in Figure 8 clearly shows a wide area of adhesive delamination in the middle MDF, and the top piece has lower signal intensity than that of the bottom piece. Thus, in general the ultrasound signal intensity reflects the IB level of each MDF board. Research needs to be done to investigate whether IB can be determined by air-coupled ultrasonic measurements as acutely as done by the tedious conventional method.

Air-Coupled Ultrasonic Inspection of Kenaf-Fiber Panels

Natural fibers may be used as a source of renewable material in composites. The fibers may come from woods, grasses or other plants, and may be blended with petroleum-based or renewable resource-based resins [9]. In the sample used in this study, kenaf fibers were blended with petroleum-based resin, formed into separate mats, and combined to make acoustic barrier panels of varying density.

Air coupled ultrasound was used to inspect such panels for delaminations between the individual mats as well as provide information regarding the intended density variability. Through transmission testing of these panels, following the guidelines presented above for other materials, readily provided data that could identify regions of interest. In Figure 9, mapping of transmitted signal amplitude is shown next to photograph of the test panel. It may be seen that while “disc” locations on the composite tended to all provide a similar range of mid-level signal amplitudes, the “node” regions could vary dramatically within the area of the test piece.

As it is critical for these products to provide a consistent level of the designer’s intended densities across the panel, the density at varying regions need to be maintained. Conceivably, such transmitted amplitude data could be used for rapid quality control purposes in panel production.

CONCLUSIONS

Air-coupled ultrasound has been successfully used to detect ponderosa pine sinker-stock lumber. Presence and general shapes of other internal lumber defects such as knots and voids (checks) can be determined by air-coupled ultrasound scanning at moderate scanning speeds. Examples also have been presented to demonstrate usefulness of the air-coupled ultrasound scanning technique to inspect wood-based composite products for quality assurance.

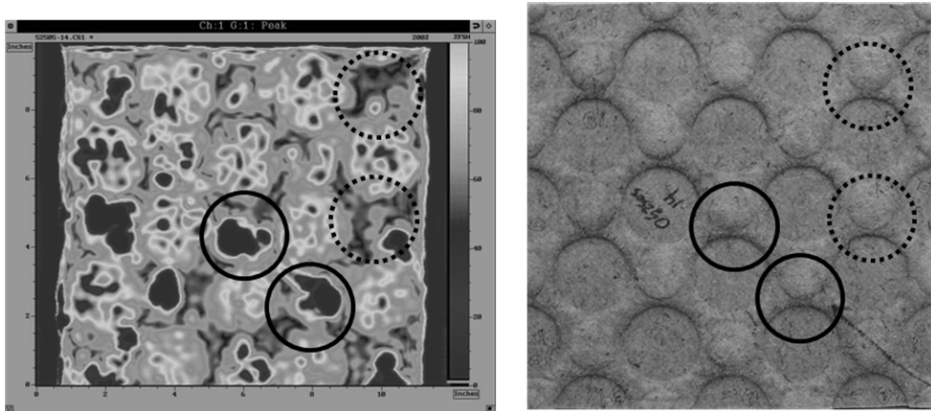


FIGURE 9. Ultrasonic C-scan of kenaf fiber composite (left) and photograph of test piece (right). Note the pronounced amplitude variation at locations of solid and dotted circles. Solid circles on the C-scan correspond to saturated signal levels for transmitted ultrasound, while dotted circles indicate very low transmitted signal. (Original pseudocolor maps convey information better.) Therefore, these four “node” regions exhibit dramatically test response and, presumably, performance.

REFERENCES

1. J. Krautkramer and H. Krautkramer, *Ultrasonic Testing of Materials*, 4th edition, Springer-Verlag, Berlin, Heidelberg, (1990).
2. *Nondestructive Testing Handbook*, Vol 7, American Society for Nondestructive Testing, Columbus, Ohio, (2007).
3. A. J. Rogovsky, "Development of ultrasonic dry-contact and air-coupled C-scan systems for nondestructive evaluation of aerospace composites", *Materials Evaluation* **50**(12):1401-1407 (1991).
4. J. M. Buckley, Air coupled ultrasound—a millennial review. *Proceedings of BINDT*, (2000).
5. V. Kommareddy, *Air Coupled Ultrasonic Measurements in Composites*. Master's Thesis, Iowa State University, (2003).
6. M. J. Anderson, P.R. Martin, and C.M. Fortunko, "Gas coupled ultrasonic measurement of stiffness moduli in polymer composite plates", IEEE Ultrasonic Symposium, B.R. McAvoy, ed, pp. 1401-1407 (1994).
7. R. Farlow, S. Kelly, and G. Howard, "Advances in air coupled NDE for rapid scanning applications", IEEE Ultrasonic Symposium, B.R. McAvoy editor, pp. 1099-1102 (1994).
8. J. J. Ellsworth, R. Schebler, N. Sanderfeld, and M.L. Kuo, "Detecting sinker-stock lumber with ultrasound measurements". *Wood & Fiber Science* **38**(1):28-35 (2006),